Inadequate Work Package Results in Water Hammer in Steam System

1

On September 28, 2005, at the Los Alamos National Laboratory (LANL), a water hammer occurred in a steam line during restoration of an isolated steam system following routine maintenance. The water hammer caused the catastrophic failure of a blind flange, the rupture of an expansion joint, and the release of steam at a temperature of approximately 340°F. Pipefitters were using a general startup procedure to restore the steam system rather than a task-specific procedure that would have properly drained water from the steam lines. There were no injuries as a result of this event. (ORPS Report NA--LASO-LANL-PHYSTECH-2005-0010; final report filed February 2, 2006)

The pipefitters were tasked with performing routine maintenance on an expansion joint and repairing a steam valve that had a leaking bonnet. The valve and expansion joint were located in a manhole. Before beginning the maintenance work, the pipefitters isolated steam to the manhole by closing appropriate steam valves in the surrounding manholes. They used double block and bleed procedures because some of the isolation valves leaked and could not completely isolate the steam.

After the maintenance had been completed, the pipefitters attempted several system blowdowns to remove any water and then began to recharge the piping with steam. As the last steam isolation valve was being cracked open, the pipefitters heard noises indicating a problem and they quickly backed away. The sounds became worse until a blind flange located in another manhole fractured, releasing large amounts of steam. The pipefitters quickly isolated the release by shutting remote valves in other manholes. Steam plant recorders indicated that the duration of the steam release was approximately 5 minutes. The damaged blind flange and ruptured expansion joint are shown in Figures 1-1 and 1-2. Water (condensate) had accumulated in the steam piping upstream of the isolation valve; when the valve was opened, the condensate flashed, causing extremely high-pressure pulses in the steam piping.

Investigators determined that the work package preparation was inadequate. The Integrated Work Document and Work Order were valid, but the procedure used to perform the work was a general "Steam Startup" procedure, which was not specifically tailored to the job the pipefitters performed. If the pipefitters had used a specific procedure, the condensate collected upstream of the isolation valve would have been drained off, and the water hammer would have been prevented.

Figure 1-1. Failed blind flange

Figure 1-2. Ruptured expansion joint shown after removal

A contributing factor was that the 1950s-era flange that failed was made of cast iron with a maximum pressure failure rating of 125 psi. LANL engineering standards require all steam system flanges to be steel with a maximum failure pressure of 150 psi. As a corrective action, LANL Utilities personnel are conducting a system-wide survey to identify and replace all nonconforming flanges.

Water hammer, also known as steam hammer, is a pressure or momentum transient in a closed system caused by a rapid change in fluid velocity. Types of water hammer include the following:

- Flashing-induced;
- Void-induced;
- Valve-induced;
- Steam-propelled water slug; and
- Condensate-induced.

Condensate-induced water hammer is the most frequently reported type of water hammer at DOE facilities. Figure 1-3 shows the distribution of water hammer occurrences reported in ORPS from January 1990 through July 2006.

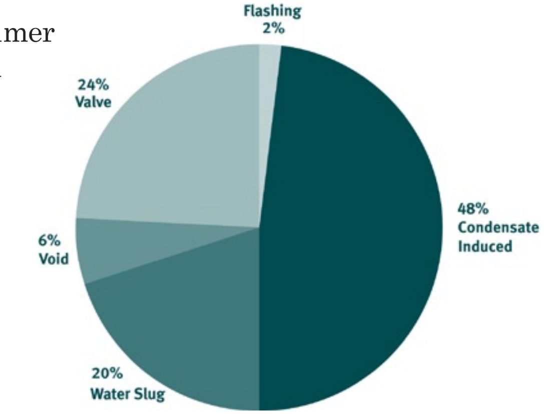

Figure 1-3. Types of water hammer events

Condensate-induced water hammer is caused by rapid condensation of steam by subcooled water. The most common type of condensate-induced water hammer is caused by steam flowing over subcooled water. The flow of steam causes ripples in the water surface. If these ripples touch the top of the pipe, a pocket of steam can momentarily be sealed off, which then condenses and collapses, causing a pressure wave (Figure 1-4).

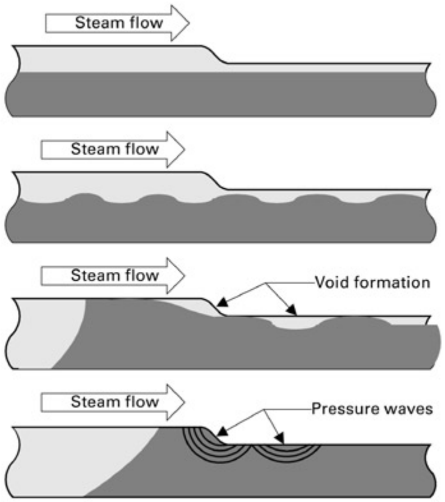

Figure 1-4. Condensate-induced water hammer in a horizontal pipe

The water hammer event at LANL was most likely caused by flashing of the condensate. Flashing-induced water hammer can occur when water moves through a pressure drop to a region where the pressure is less than the vapor pressure of the water. Some water will flash to steam and can propel slugs of water, generating a pressure wave or momentum change (Figure 1-5).

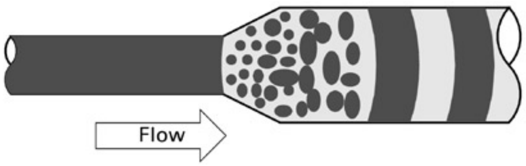

Figure 1-5. Condensate flashing in a section of piping

Although rare, water hammer events have resulted in fatalities at DOE facilities. On June 7, 1993, a water hammer caused a valve rupture and fatal injury at Hanford. (ORPS Report EM-RL--WHC-WHC300EM-1993-0022) A Type A Accident Investigation Board identified inadequacies in operating practices and procedures, lessons learned, training, safety implementation, design, and oversight.

In 1986, a condensate-induced water hammer at Brookhaven National Laboratory resulted in two fatalities and two severe injuries. A Type A Accident Investigation Board determined that steamfitters used an in-line gate valve to remove condensate rather than the drains installed for that purpose. There were no written instructions for warming and activating the steam lines, and no formal training was provided to the steamfitters involved in the accident.

Most water hammer events occur in steam systems; however, it is not uncommon to experience this phenomenon in non-steam fluid systems. For example, at Hanford, a water hammer occurred when an operator quickly closed a quarter-turn ball valve after flushing fire hydrants. The pressure wave resulted in minor equipment damage. (ORPS Report EM-RL--WHC-CENTPLAT-1994-0049)

At the Nevada Support Facility, a water hammer occurred in the cold loop side of the HVAC cooling system, rupturing a 14-inch supply pipe, a 10-inch return pipe, and several 8-inch pump lines. The initial cost estimate ranged from $60,000 to $100,000. The cause has not been determined. (DP-NVOO--GONV-GONV-2000-0007)

Preventing Water Hammer

- Do not introduce steam into piping without verifying that there is no liquid water present.
- Warm cold steam piping slowly, keeping steam trap blowdown valves open.
- Walk down steam systems and check for proper location, distribution, and sizing of steam traps and blowdown valves for startup and operation.
- Inspect steam traps frequently for proper operation.
- Be cautious when cracking open valves to avoid condensation-induced water hammer because steam-propelled water slugs can be formed at very low flow conditions.
- Verify that steam traps are operating properly before opening steam line valves. On startup, open blowdown valves fully and leave them open until liquid stops flowing.
- When feasible, operate valves remotely using mechanical extension linkages, reach rods, or power-operated valves. Ensure that reach rods and extension linkages are properly maintained.
- Inspect piping systems for sagging. If necessary, install steam traps at low points or repair the sag.
- Check and repair piping insulation to reduce condensate formation in the piping and to save energy.
- All isolation valves should have bypass systems. Remember that bypass operations do not prevent water hammer if condensate is present.

Water hammer events are commonly caused by the following failures.

- Failure to ensure that water (condensate) has been removed using steam traps and drains before admitting steam into the piping system.
- Failure to properly maintain steam traps, drain, and blowdown valves in an operable condition.
- Failure to ensure that an adequate number of steam traps and drains have been installed at locations conducive to condensate removal.
- Failure to operate system valves properly and failure to use bypass valves to safely warm system piping downstream of isolation valves.
- Failure to use procedures specifically written for the restoration and operation of the steam system.

These events underscore the importance of safely operating fluid systems in order to prevent water hammer, which can cause severe piping and equipment damage. Water hammer can also result in the uncontrolled release of hazardous energy (e.g., hot water and steam), causing serious injury or death. These types of events can be prevented with proper job planning, adequate procedures, correctly designed and maintained equipment, and sound understanding of steam and water conditions.

KEYWORDS: *Water hammer, pipe break, steam leak, rupture, procedure, work package, maintenance*

ISM CORE FUNCTIONS: *Define the Scope of Work, Analyze the Hazards, Develop and Implement Hazard Controls, Perform Work within Controls*